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OPERATIONAL STUDY OF CIRCULATING FLUIDIZED BED STEAM GENERATOR

S. BHARATH SUBRAMANIAM

Assistant Professor, Mechanical Engineering, SRM University, Kattankulathur, Chennai Tamilnadu,India

ABSTRACT

The paper aims at studying the operation of a lignite fired Circulating Fluidized bed Combustion steam generatorof 250 MW capacity located at NeyveliinTamilnadu in South India. Circulating fluidized bed combustion(CFBC) is a techno-economical alternative to conventional pulverized coal fired combustion. It is a clean coal technology and is environment friendly. From the proximate analysis,the lignite consisted of moisture (50%), sulphur (0.70%), ash (8.50%). From the ultimate analysis, the elemental composition were carbon (27.50%), hydrogen (2.20%), sulphur (0.70%) and oxygen (10.40%), nitrogen (0.20%) were found. The operational study was doneand the particle size was one of the main factor for the efficiency. Finer particles consume auxiliary power while coarser particles due to their inertia are difficult to entrain.

KEYWORDS: Circulating Fluidized Bed Combustion (CFBC), Pulverized Coal Fired Combustion, Clean Coal Technology, Proximate Analysis, Ultimate Analysis & Inertia

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Original Article

INTRODUCTION

Circulating Fluidized bed combustion (CFBC) steam generator is equipment, used for generating steam by burning the fossil fuels in a furnace where finer solids are transported through the furnace with a velocity higher than the terminal velocity of the particles. The solids, leaving the furnace is separated by a solid-gas separator (cyclone) and is circulated back to the furnace through the down comer, seal loop, spiess valve and the return leg. The primary air is fed through the grate of the furnace and the secondary air is fed from the sides at a height above the furnace floor level. The fuel particles undergo combustion in the furnace generating heat. The heat is absorbed by the water and the rest is absorbed in the convective section located downstream known as the convective pass.

The Circulating Fluidized bed combustion (CFBC) technology has many inherent features like fuel flexibility, lower SO_x, NO_x emission, higher combustion efficiency, higher heat transfer rate etc. Also, the temperature is uniform (800-950^0 C) throughout the combustor leading to uniform thermal strain on the material and the temperature is below the ash fusion temperature. Auxiliary power consumption and complexities of fluid dynamics are some of the issues. Despite its issues the competitive advantage in terms of overall economy makes the technology a viable one for industrial applications.

THE THERMAL SYSTEM

The Circulating Fluidized Bed (CFB) unit consists of the combustor, water and steam system, air and flue gas system, fuel and ash system, auxiliary systems like gas analysers, feeding system, solid handling system etc.

The CFB combustor consists of the furnace, cyclone and circulating system (down comer, seal loop, spiess valve, the return leg and the Fluidized bed heat exchanger (FBHE)). The convective section has the reheater coils. The combustion takes place in a vertical furnace in which the fluidization occurs. The fuel is fed into the sealpot return legand is combusted at 800 to 850^0 C.

Table 1:. Dimensions of the CFB Unit

DIMENSIONS OF THE COMBUSTOR	**Width (M)**	**Depth (M)**	**Area (m^2)**	**Fuel Heat Input (Mkcal/Hr)**	
	11.840	16.240	3114	697	
CONVECTIVE PASS	**Convective Pass Wall Area (m^2)**				
	1364				
SUPERHEATER	Stage I		FBHE superheater (m^2)		1045
	Stage II		FBHE superheater (m^2)		1045
	Stage III		FBHE superheater (m^2)		1045
	Stage IV		Final superheater (m^2)		3688
	Total superheater surface area (m^2)				**6823**

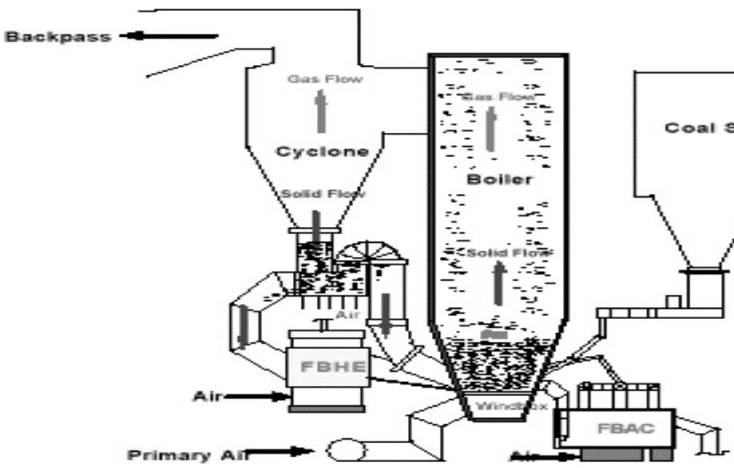

Figure 1: Schematic of a CFBC unit

Table 2: Steam Parameters

MAIN PARAMETERS									
PARAMETERS		**UNIT**	**BMCR**	**TMCR**	**PARAMETERS**		**UNIT**	**BMCR**	**TMCR**
AMBIENT TEMPERATURE		^{0}C	32	32					
MAIN STEAM	Flow at MSSV outlet	t/hr.	845	758.2	**REHEAT STEAM**	Hot reheat flow at the header outlet	t/hr.	716.5	668.8
	Pressure at MSSV outlet	kgf/cm^2 (g)	175	173.9		Hot reheat pressure at the header outlet	kgf/cm^2 (g)	46.2	43.1
	Temperature at MSSV outlet	^{0}C	540	540		Hot reheat temperature at header outlet	^{0}C	540	540

OPERATIONAL STUDY

The combustion air system consists of two primary air fans, two secondary air fans, rotary piston blower andempty chambers.Primary air is used to remove the moisture in the fuel. Secondary air provides the air for combustion and fluidizing air. Induced draft fan absorbs the air and the exhaust gas is expelled out of the stack to the atmosphere.

Table 3: Fan data

FAN	NUMBER	FLOW PER FAN (m^3/s)	PRESSURE (mbar)	TEMPERATURE (^0C)
PA fan	2	82.03	310	45
SA fan	2	83.80	150	45
ID fan	2	318.3	48	146

Table 4: Blower data

BLOWER	NUMBER	FLOW PER BLOWER (m^3/s)	PRESSURE (mbar)	TEMPERATURE (^0C)
Sealpot	5	2552	400	45
Empty chamber	5	2388	500	45
Bundle chamber	5	19500	800	45
Exit chamber	2	6500	250	45
Seal and purge	2	5062	950	45
Ash cooler	2	6215	350	45

Blowers are used for medium pressure applications. Combustor, cyclone, fluidized bed heat exchanger and the seal pot form an integral part of circulating fluidized bed combustion system. In the combustor, the fuel is burnt. Ash is carried out of the combustor along with the flue gas. The solids and the flue gas are routed to the cyclone where solid-gas separation occurs. The solid particles are circulated back to the combustor through the seal pot. The finer ash along with the flue gas then enters the convective pass. These finer particles are removed in the electrostatic precipitator. In the fluidized bed heat exchanger (FBHE) the heat of the ash is utilized by the superheater, reheater for the steam generation. The cooled ash is returned to the combustor. The downward taper in the combustor ensures constant gas velocity. A grate equipped with nozzle forms the bottom portion of the combustor. The nozzles are arranged in offset.

The secondary air is fed through the secondary air injection nozzles. Nozzle ensures optimum distribution of the air over the combustor cross section. There are 1800 nozzles in the combustor.The primary air fan increases the air pressure suitable for fluidizing the ash inventory of the combustor and overcome the pressure drop across the nozzle and back pressure of the CFB combustor. The primary air is fed through the air heater and the wind box. Secondary air consists of air from fan, fluidizing air of the FBHE, sealpot, ash coolers, seal and purge air. It is fed to the combustor at various levels. The secondary air is preheated in the combustion air preheater and controlled in such a way that the required air fuel ratio is attained. The flow rates are controlled by respective dampers.

The secondary air fan maintains the air pressure controlled by the inlet guide vane of the fan. Fluidizing air is sent to the ash cooler, seal pot and fluidized bed heat exchanger (FBHE) and is compressed and injected into the combustor. As the flow rate of the fluidizing air increases, the particles start rising in the bed and gets entrained. The total air flow rate is calculated. The air flow includes primary air through nozzles, oil lances, secondary air, fluidizing air of the ash coolers, seal pots, seal and purge air etc. The hot ash laden flue gases leaving the combustor enter the cyclone where solid-gas

separation occurs. Cyclone is refractory lined consisting of a cylindrical top section and a conical bottom section tapering downward. The ash circulates to the combustor through the seal pots. Only a fraction of the finer ash leaves the cyclone along with the flue gas. The vortex finder improves the solids separation and promotes solids circulation in the system. The seal pot which is in the downstream of the cyclone has an erosion resistant lining. Fluidizing air is sent to the seal pots. The ash from the cyclone enters the combustor through the seal pots. The ash circulation rate to the fluidized bed heat exchanger is controlled by the spiess valve. The fluidizing air to the seal pot is given by the seal pot blower. Air distribution to the nozzles is accomplished by the wind box located underneath the seal pot.

Fluidized bed heat exchanger (FBHE) have refractory lined walls. It consists of empty chamber to steady the ash flow entering the heat exchanger and bundle chamber with heat transfer bundles. In the chambers ash is fluidized by means of constant airflow through the nozzle grates supplied by the rotary piston blowers. The air flow rate is controlled by dampers. Several CFBC steam generators have separate Fluidized Bed Heat Exchanger (FBHE). The FBHE can be used as evaporative heat transfer surfaces as well as superheat and reheat surfaces depending upon the design.

Flue gas system consists of the convective pass, air heater, overpressure relief damper, particulate removal system, induced fan system and stack. It serves the function of heat transfer to the water and steam system as well to the combustion air system and

removes the particulate matter in the flue gas to environmentally acceptable levels. It also maintains the required temperature in the boiler. Limestone is added to the fluidized bed to capture the sulphur at the bottom. The reactions that occur are known as the calcination loss and sulphation credit reactions. Magnesium carbonate can also be added to the bed.

CALCINATION LOSS

This reaction is endothermic as it absorbs heat from the combustor.

$$CaCO3 \rightarrow CaO + CO2 \tag{1}$$

The calcination loss can be calculated by

$$\text{Calcination loss} = \frac{\text{Feed rate of CaCO3 X 1830}}{\text{Fuel feed rate X GCV}}$$

SULPHATION CREDIT

This reaction is exothermic in nature and adds heat to the thermal system. When the calcined limestone (CaO) reacts with sulphur dioxide, calcium sulphate is formed according to the reaction:

$$CaO + SO2 + \frac{1}{2}\,O2 \longrightarrow CaSO4 + 15141\,\frac{kJ}{kg} \tag{2}$$

$$\text{Sulphation credit} = \frac{\text{kg of sulphur converted X15141}}{\text{kg of fuel fed X GCV}}$$

OPERATIONAL DATA

Table 5: Operational Parameters

DESCRIPTION	DATA
Ambient Temperature	32 C
Table 5: Contd.,	
Main steam Temperature	540 C

Reheat steam Temperature	540 C
Main steam Flow	845 t/hr.
Reheat steam Flow	716.5 t/hr.
Main steam Pressure	172 ata (g)
Reheat steam Pressure	45.3 ata
Fuel feed rate	263 t/hr.
Feed water temperature	256 C

Table 6: Process data

DESCRIPTION	DATA
Heat release per burner	36 M kcal/hr. (HFO) 11.7 M kcal/hr. (LDO)
Number of burners per boiler	4
Combustion air flow	40 t/hr.
Combustion air temperature	30 C / maximum 300 C
Combustion air pressure at the burner inlet	1800 mm of water column
Draft loss	196 mm of water column

Table 7: Electrostatic Precipitator Data

DESCRIPTION	DATA
Gas flow rate to ESP	328.3 nm^3/s
Gas temperature at the ESP inlet	140 C
Dust concentration at the ESP inlet	28.56 g/nm^3

Table 8: Air Heater Data

DESCRIPTION	UNIT	BMCR	TMCR
Flue gas quantity	kg/hr.	1363135	1234935
Gas temperature at TAPH inlet	degree C	293	288
Gas temperature at RAPH inlet	degree C	TAPH exit temperature	
Gas temperature at the outlet	degree C	140 (max)	138

RESULTS AND DISCUSSION

FLUE GAS ANALYSIS

Flue gas carry large amount of heat which can be utilized to improve the performance of the steam generator. Oxides of sulphur and nitrogen can be controlled. No flue gas desulphurization and flue gas denitrification plant is required for CFBC combustors as sulphur is captured in the combustor using limestone.

Table 9: Flue gas Composition

GAS	% BY VOLUME
N_2	62.5
CO_2	11.5
H_2O	21.9
O_2	4.2
SO_2	66 ppm

OPERATIONAL GRAPHS

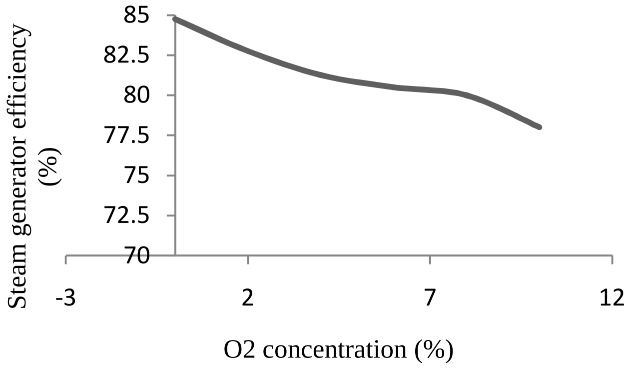

Figure 2: Oxygen Concentration vs. Steam Generator Efficiency

As the oxygen concentration increases the steam generator efficiency drops. Excess air is required to complete the combustion. It has to be kept minimum. It is supplied for complete combustion. Combustion efficiency is enhanced by supplying air in excess. It increases the heat losses but minimizes the CO formation. It is measured from the oxygen in the flue gas leaving the stack. Atmospheric air contains 21% of oxygen by volume.

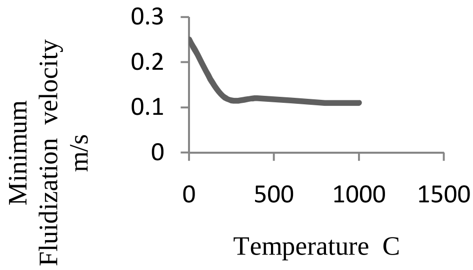

Figure 3: Minimum Fluidization Velocity vs. Temperature

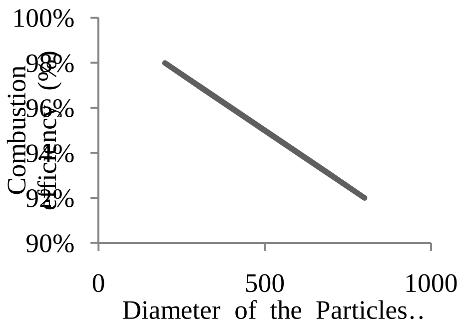

Figure 4: Combustion Efficiency vs. Particle Size (Microns)

Combustion is a process of burning the fuel in order to obtain heat energy in a controlled manner. For a good combustion to take place temperature, turbulence and time are essential. The heat energy is utilized for various applications which includes boilers, engines, etc. The combustion efficiency of a circulating fluidized bed steam generator varies from 98% to 99.9%.Also, it has better solid-gas mixing i.e. turbulence is provided for the combustion. Fluidized bed combustor is metallurgic ally stable. The heat transfer coefficient between a surface and a gas solid suspension is a function of particle convection, gas convection and radiation.

$$h = h_P + h_g + h_r$$

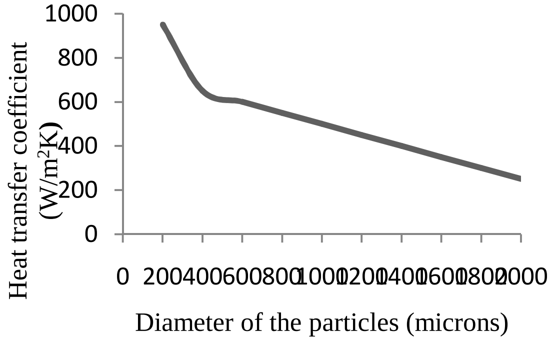

Figure 5: Heat Transfer Co Efficient vs. Particle Size

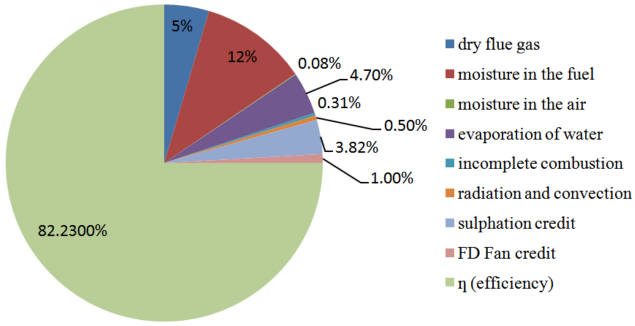

Figure 6: Heat Losses and Credits in the CFB Steam Generator

Heat credits include sulphation credit and forced draft fan credit. A fluidized bed of particle is capable of exchanging heat effectively with the gas because of the large surface area exposed by the particles (3000 – 45000 m^2 / m^3). Highest rates of heat transfer between the fluidized bed and the surface are obtained when the particle residence time is less. Heat transfer is maximum when the particles are finer.

CONCLUSIONS

The operational parameters of the lignite fired circulating fluidized bed combustion steam generator were studied. It was found that particle size plays an important role in the efficiency of the steam generator. Finer particles exhibit better heat transfer characteristics than the coarser particles. However, coarser particles are easier to fluidize. Hence optimized particle size has to be chosen depending on the steam generator capacity. The circulating fluidized bed combustion is a techno-economical solution to today's demand for power as long as the coal is available and has an inherent environment friendly nature.

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ABBREVIATIONS AND SYMBOLS

CFBC – Circulating fluidized bed combustion

FBHE – Fluidized bed heat exchanger

TAPH – Tubular air preheater

RAPH – Regenerative air preheater

HFO – Heavy furnace oil

LDO – light diesel oil

h – heat transfer coefficient (W/m^2K)

h_P – particle heat transfer coefficient (W/m^2K)

h_g – gas heat transfer coefficient (W/m^2K)

h_r – radiation heat transfer coefficient (W/m^2K)